

Evolution of the periodicities in 2S 0114+650

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Abstract

We have analysed nine years of data from the All Sky Monitor on the *Rossi X-ray Timing Explorer* for 2S 0114+650 to study the evolution of its spin, binary and super-orbital periods. The spin history of the neutron star in this system exhibits torque reversals lasting ~ 1 yr. The newly discovered super-orbital period has remained stable over the 9-yr span, making 2S 0114+650 the fourth known system to exhibit stable super-orbital modulation. We compare its super-orbital period evolution with those of the other three such systems.

Key words: X-rays: binary - stars: neutron - accretion: accretion discs - stars: individual (2S 0114+650)

1 Introduction

The high mass X-ray binary 2S 0114+650 (Per X-2) was discovered in 1977, and subsequently the optical donor star LSI +65° 010 was classified as a B1 Ia supergiant at a distance of 7.0 ± 3.6 kpc (Reig et al. 1996). Ashok et al. (2006) recently confirmed this classification through near infrared observations at the Mt Abu observatory. The binary orbital period of 11.6 d was determined in X-rays by Corbet, Finley & Peele (1999) using data from the All Sky Monitor (ASM) aboard the *Rossi X-ray Timing Explorer (RXTE)*. They also confirmed a periodicity of ~ 2.7 h, attributing it to emission from a highly magnetised neutron star. The 2.7 h spin period is by far the slowest known for an X-ray pulsar, making 2S 0114+650 the first in a new class of super-slow rotators. Farrell, Sood & O'Neill (2006) recently reported a 30.7 d super-orbital period in ~ 8.5 yr of *RXTE* ASM data, making 2S 0114+650 the fourth X-ray binary exhibiting a stable super-orbital modulation.

2 Data Reduction & Analysis

Archived data from the *RXTE* ASM for the X-ray binaries 2S 0114+650, SS433, Her X-1, and LMC X-4 for the period MJD 50135 (1996 February 22) to MJD 53635 (2005 September 22), were used in these analyses. We used one-day average light curves for the analysis of the orbital and super-orbital periods, and 90 s dwell data to investigate the evolution of the spin period (Farrell et al. 2006). A Dynamic Power Spectrum approach was used for the orbital and super-orbital periods (e.g. Clarkson et al. 2003) where the Lomb-Scargle periodogram was applied to overlapping light curve sections, producing a sliding ‘data window’ sensitive to long-term changes in any modulation present in the light curves. We used a window length of 400 d and a shift of 100 d for the analysis of the orbital and super-orbital periods. For the 164 d super-orbital period of SS433 we used a window length of 800 d. C-band data (5.0 - 12.0 keV range) were used for 2S 0114+650 and SS433 to account for the excessive noise observed in their low energy channels. The combined 1.5 - 12.0 keV data were used for the other sources. The resulting power spectra were normalised to the highest power in the period range of interest.

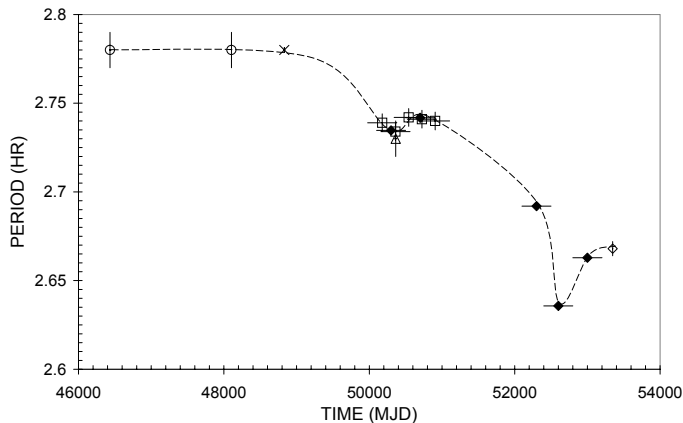


Fig. 1. The evolution of the ~ 2.7 h spin period of 2S 0114+650. See Farrell et al. (2006) for details of where the individual data points were taken from.

3 Results & Discussion

The neutron star spin evolution in 2S 0114+650 is shown in Fig. 1. Data points are shown for only when the spin period power exceeded the 99% significance level for this low flux source. Two episodes of torque reversal, each lasting ~ 400 d, are embedded in a general spin-up trend. 2S 0114+650 is expected to be a wind-fed accretor, and the association of the torque reversal episodes with the formation of a transient accretion disc is unclear. The observed average \dot{P}/P based on *RXTE* ASM data is $3.4 \times 10^{-3} \text{ yr}^{-1}$, a value which has been

independently confirmed by Bonning & Falanga (2005) using *INTEGRAL* observations. This value is an order of magnitude less than the value expected when the spin up is caused by a disc-fed system (Nagase 1989).

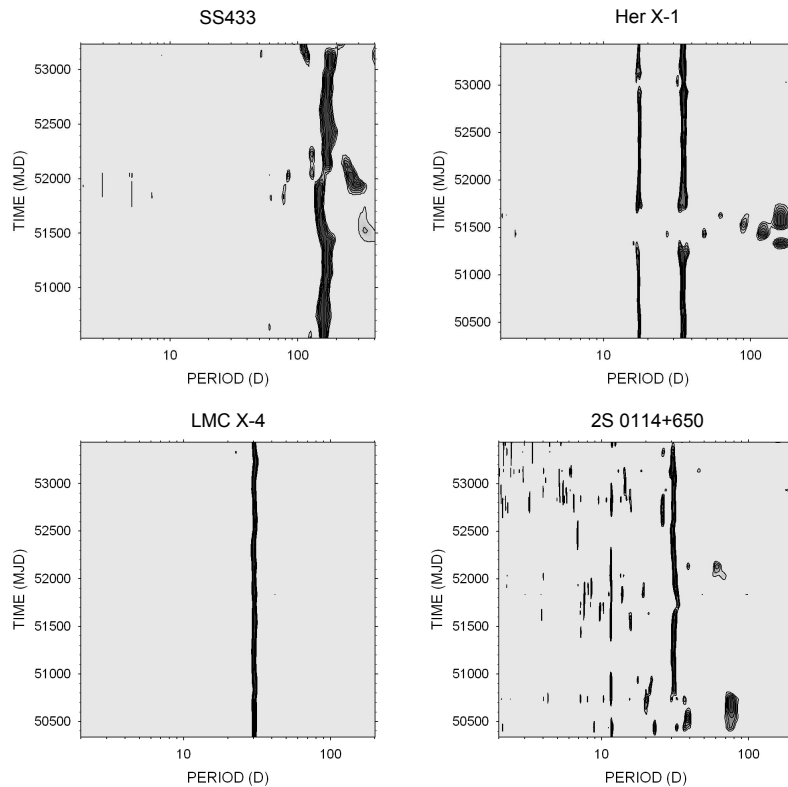


Fig. 2. Dynamic Power Spectra of the four stable super-orbital periods.

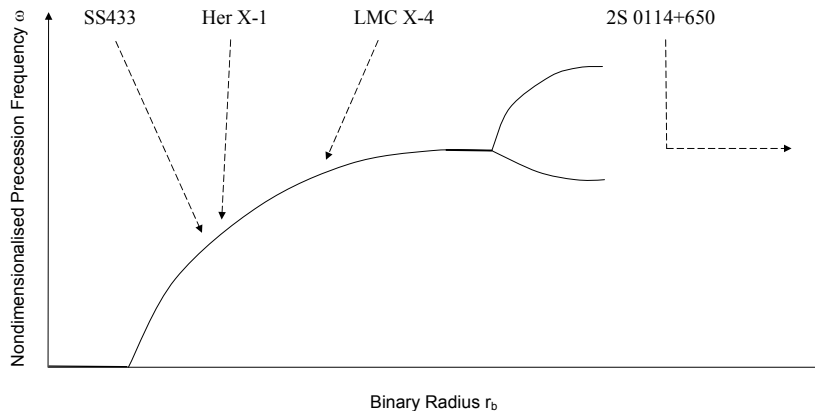


Fig. 3. Schematic bifurcation diagram for radiation-driven warping (Figure 14 from Clarkson et al. (2003)). With a binary radius of $18.8 \times 10^6 \text{ GM}_1\text{c}^{-2}$, 2S 0114+650 lies far off to the right of this diagram.

The change in the orbital period cannot be tightly constrained by the ASM data for 2S 0114+650. An upper limit value for \dot{P}_{orb}/P_{orb} of $\lesssim 10^{-3} \text{ yr}^{-1}$ is obtained.

To date four stable super-orbital periods have been identified in X-ray binaries: SS433, Her X-1, LMC X-4, and now 2S 0114+650. The 164 d period in SS433 has been explained by jet precession (Margon 1984). Clarkson et al. (2003) showed that the stability of the 35 d and 30 d super-orbital periods in Her X-1 and LMC X-4 were consistent with the radiation-driven warping of an accretion disc. They demonstrated in Fig. 14 of their paper that the number of stable precession solutions was dependent on the binary separation. SS433, Her X-1 and LMC X-4 all lie in the stable mode-0 precession region, while 2S 0114+650 lies far to the right of the mode 1 region (Fig. 3), indicating that two or more steady solutions are possible and that the system should precess at a combination of these warping modes. Thus, if the 30.7 d super-orbital period in 2S 0114+650 is due to the precession of a radiatively warped accretion disc, it should not exhibit the long-term stability that has been observed.

4 Acknowledgements

This research made use of quick-look data provided by the *RXTE* ASM team at MIT and GSFC and data obtained through the High Energy Astrophysics Science Archive Research Centre Online Service, provided by NASA/GSFC.

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